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ONE-DIMENSIONAL CLOUD MICROPHYSICAL MODELS FOR CENTRAL EUROPE AND THEIR OPTICAL PROPERTIES

OCTOBER 1980

By
RICHARD D. H. LOW

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US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

One-dimensional microphysical models for six different cloud types are proposed. These models were formulated by making use of Khrgian-Mazin's one-parameter modified gamma distribution to judiciously mate the Russian measurements of cloud liquid water content and mean radius profiles to the German observations of various cloud types. With the drop-size spectra of the clouds thus determined as a function of height, calculation of their optical properties became straightforward.

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20. ABSTRACT (cont)

Separate regression relationships were established for the six model clouds, giving liquid water content and mean radius as a function of height above the cloudbase by the method of least-squares fit. It is from these relationships that the drop-size distribution may be derived for any level in a cloud of interest, and hence its spectral extinction coefficients at any wavelengths, in turn, from the distribution. A close examination of these coefficients in the visible and infrared window regions for each of the cloud types revealed that as a function of height they were well represented by polynomial relationships of 3 to 6 degrees. Regression coefficients for these relationships are presented in three separate tables.

The six one-dimensional model cloud types proposed herein may fill the gap which has long been felt in the modeling community and which is also found in our present electro-optical systems atmospheric effects library.

CONTENTS

1. INTRODUCTION

Lacking at present in the electro-optical systems atmospheric effects library (EOSAEL) are cloud optical models suitable for use in the design, development, and evaluation of the various types of EO devices or in war games. This lack, however, does not mean that cloud models do not exist elsewhere. In fact, cloud models are readily found in some old cloud physics books, for example, in Fletcher,[1] Khrgian,[2] and Mason.[3] Once a model cloud is selected, determination of its extinction and backscatter characteristics at any desired wavelength or spectral band is fairly straightforward. Cato et al[4] in an extensive survey of published cloud drop-size data adopted the model clouds derived by Diem[5] from his own cloud measurements in Germany and calculated their extinction and backscatter properties at three laser wavelengths. Using Diermendjian's[6] three-parameter gamma distribution function and more recent microphysical data, Tampieri and Tomasi[7] proposed a number of cloud and fog models for optical calculations. Whichever models we may use, we should realize that the microphysical properties of clouds, and hence their optical properties as well, do vary with time, height, and geography. Therefore, whatever microphysical features we may ascribe to a cloud, we may be reasonably certain that such features can be found in that cloud either at a certain time or at a certain height or both. However, these models will only produce homogeneous clouds.

This report seeks to generate one-dimensional inhomogeneous clouds, that is, cloud microphysical or optical properties as a function of height. Since we are basically concerned with Europe's adverse weather in general and Germany's in particular, we shall again adopt Diem's nonprecipitating water cloud models supplemented by the Russian versions of cumulus clouds. The following section discusses our statistical approach to cloud modeling. Section 3 describes the data source and our manipulations, and section 4 gives the microphysical and

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[1]N. H. Fletcher, 1962, The Physics of Rainclouds, Cambridge University Press, London, 386 pp

[2]A. Kh. Khrgian, Editor, 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pp

[3]B. J. Mason, 1971, The Physics of Clouds, Oxford University Press, London, 617 pp

[4]G. A. Cato, L. W. Carrier, and K. J. von Essen, 1955: Laser Systems Study, Part III: Effects of Clouds, EOS Report 4440-Final III (AD-479487), Electro-Optical Systems, Inc., Pasadena, CA., 92 pp

[5]Max Diem, 1948, "Measurements of the Size of Cloud Elements, Part II," Meteor Rund, 1:261-273

[6]D. Diermendjian, 1964, "Scattering and Polarization Properties of Water Clouds and Hazes in the Visible and Infrared," Appl Opt, 3:187-196

[7]F. Tampieri and C. Tomasi, 1976, "Size Distribution Models of Fog and Cloud Droplets in Terms of the Modified Gamma Distribution," Tellus, 28:333-347

optical properties of our model clouds. The final section discusses the results of our calculations and presents some concluding remarks.

2. STATISTICAL APPROACH TO CLOUD MODELING

As noted by Khrgian[2] and again by Twomey,[8] a variety of empirical and analytical expressions for drop-size spectra have been proposed for studying cloud dynamical and microphysical processes, but unfortunately the theory of droplet growth has not yet succeeded in indicating what the general form of drop-size distribution should be. Since one form is not much better or worse than the other in fitting a given distribution, according to an exhaustive investigation by Khrgian and Mazin,[9] it would be in harmony with human nature to select one which is the most convenient to use. In this light, we chose Khrgian-Mazin's one-parameter gamma distribution[10] which is given by

$$n(r) = Ar^2 e^{-br} , \qquad (1)$$

where $A = 1.4503 \times 10^6 \; W/(\bar{r})^6$ and $b = 3/\bar{r}$.

In this expression, W is the liquid water content (LWC) in grams per cubic meter and $\bar{r}$ the mean radius in micrometers. Thus equation (1) can also be expressed by

$$n(r) = 1.4503 \times 10^6 \frac{W}{(\bar{r})^6} r^2 \, e^{-3r/\bar{r}} \qquad (2)$$

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[2]A. Kh. Khrgian, Editor, 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pp

[8]S. Twomey, 1977, Atmospheric Aerosols, Elsevier, NY, 302 pp

[9]A. Kh. Khrgian and I. P. Mazin, 1956, "Analysis of Methods of Characterization of Cloud Droplet Distribution Spectra," Trudy Tsen Aero Obs, 17:23-30 (English version)

[10]A. Kh. Khrgian and I. P. Mazin, 1952, "Distribution of Drops According to Size in Clouds," Trudy Tsen Aero Obs, 7:56-61 (English version)

and

$$W = 9.3084 \times 10^{-6} N \bar{r}^{3} , \tag{3}$$

where N is the number concentration per cubic centimeter, assuming the density of a water droplet to be unity.

Equation (2) indicates that a drop-size spectrum can be readily generated when its mean radius and LWC (or number concentration) are given.

3. DATA SOURCE AND TREATMENT

The very detailed description and analysis of the microphysical data of a number of cloud types, in Khrgian's chapter on the "Microstructure of Clouds,"[2] show the tremendous amount of work the Russians had done in cloud measurements over their European territory. Of particular interest to us are the three tables (28, 29, 30) in that chapter giving the average LWC of four cloud categories (namely, stratus-stratocumulus [St-Sc], altostratus-nimbostratus [As-Ns], cumulus humilis [Cu hum], and cumulus congestus [Cu cong]) as a function of height above the cloudbase at temperatures above as well as below freezing. For ease of extinction calculations, our investigation was restricted to water clouds only. Table 1 was adapted from Mason[3] in consideration of those cloud types whose water contents are available, and table 2 was extracted from Koenig and Schutz[11] to show the gross features of these clouds.

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[2] A. Kh. Khrgian, Editor, 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pp

[3] B. J. Mason, 1971, The Physics of Clouds, Oxford University Press, London, p 112

[11] L. R. Koenig and C. Schutz, 1974, A Temperate-Zone Cyclonic Storm Model, R-1534-PR, Rand, Santa Monica, CA, 42 pp

TABLE 1. CHARACTERISTICS OF CLOUD-DROPLET POPULATIONS. MEAN RADIUS ($\bar{R}$), MODE RADIUS (R_{mod}), NUMBER CONCENTRATION (N), LWC, AND MAXIMUM RADIUS (R_{max}).

Cloud Type	$\bar{R}$ (μm)	R_{mod} (μm)	N (cm^{-3})	LWC ($g\ m^{-3}$)	R_{max} (μm)
From Germany					
Stratus	6	4	260	---	22
Altostratus	5	4.5	450	---	13
Nimbostratus	6	4	330	---	20
Stratocumulus	4	3.5	350	---	12
From Russia					
Cumulus humilis	5	4.3	310	0.15	--
Cumulus congestus	8	5.5	95	0.45	40

In transplanting, with appropriate modification, the Russian-measured LWC versus heights to fit the German-observed clouds, we assumed that clouds of the same type are subject to the same *kind of dynamical and microphysical* formation processes despite their outward differences in microphysics brought about by geography or environment.

As a first step, LWC was plotted against height for each cloud category. An examination of the scatter diagrams revealed that the data points could be well fitted with a second-degree polynomial relating liquid water to cloud height. Four regression equations were derived.

The correlation coefficients of the equations were as follows: Cu hum, 99 percent; Cu cong, 97 percent; St-Sc, 93 percent; and As-Ns, 84 percent. Figure 1 illustrates the least-squares fit for Cu hum. When the mean radius and the number concentration are given, (table 1), the LWC of a cloud can be estimated according to equation (3). A comparison of the water contents so obtained for the four cloud types from Germany with those calculated from the regression equations for St-Sc clouds and for As-Ns clouds at some height near the midpoint between the cloudbase and the height where the LWC was a maximum showed that the LWC profile for the Russian St-Sc clouds was about right for the German Sc cloud but somewhat too dry for the German St cloud. An upward adjustment of the profile became necessary. Moreover, noting that the Russian St cloud has a mean radius of 5.0μm in Khrgian's table 18 (or 1μm smaller than that of the German St cloud), the German St cloud was estimated to be about 70 percent wetter, a not unlikely occurrence considering the fact that Germany is much further south than the European part of Soviet Russia and hence much warmer. The LWC profile, or the regression equation for the St-Sc clouds, was adjusted by 70 percent, thereby giving one expression for the St cloud and another for the Sc. Similar comparisons were made between the German As-Ns

TABLE 2. GROSS CHARACTERISTICS OF CLOUDS

Cloud Type	Formation	Horizontal Extent	Height of Base (km)	Thickness (km)	Homogeneity
Stratus	Cooling and slow upward turbulent transport	Up to 10^6 km^2	0.1 to 1	0.2 to 1	Fairly homogeneous but patchy sometimes
Altostratus	Large-scale lifting associated with fronts	Up to 10^5 km^2	3 to 5	1 to 2	Relatively homogeneous spatially
Nimbostratus	Large-scale forced lifting due to fronts	Wide, up to 700 km by 2000 km	0.1 to 1	Several	Uniform in horizontal properties
Stratocumulus	Transformation from St or Cu	Variable, about 10^4 km^2	0.6 to 1.5	0.2 to 1	Inhomogeneous spatially
Cumulus humilis	Convection	10^4 to 10^6 m^2 per single element	0.8 to 1.5	1 to 2, may develop into Cu cong	Inhomogeneous
Cumulus congestus	Convection	10^4 to 10^6 to m^2 per element but can cover 10^6 km^2 collectively	0.8 to 1.5	To several	Very inhomogeneous

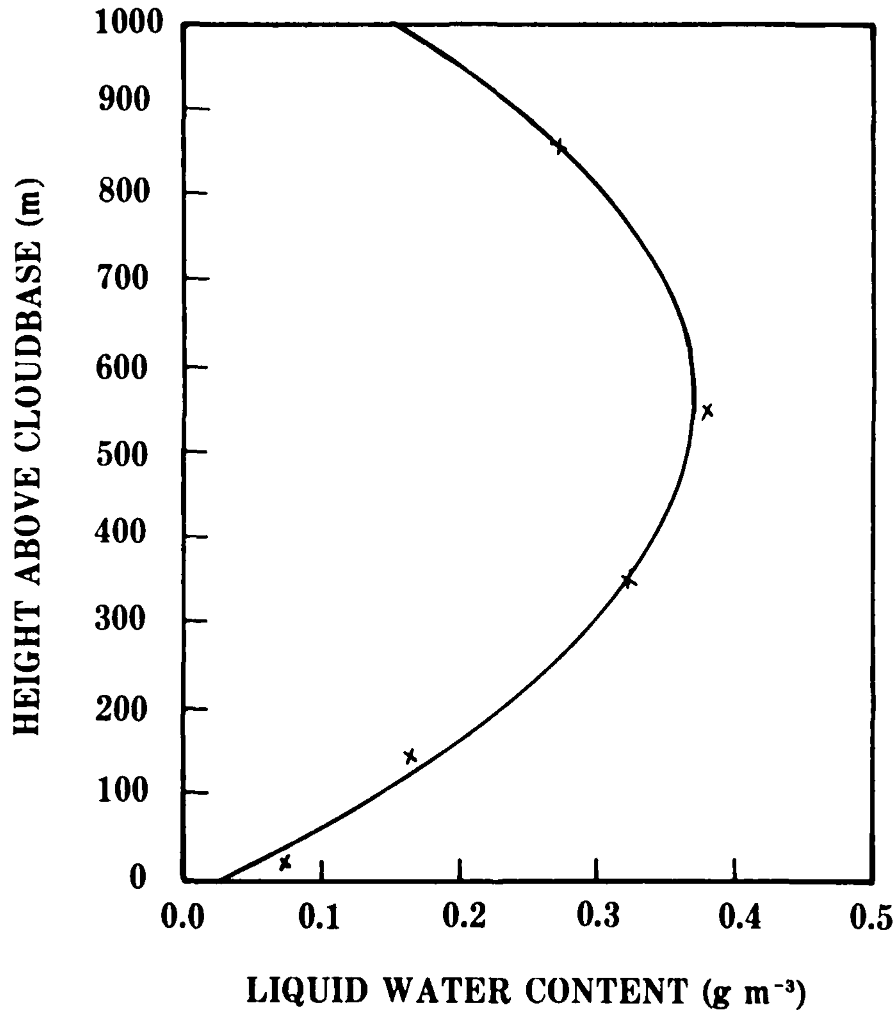

Figure 1. Least-squares fit to the observed average LWC of Cu hum versus height above the cloudbase.

clouds and their Russian counterparts. Again, adjustment was found necessary--thus a 35 percent increase for the As cloud and a 100 percent increase for the Ns. As a result of these adjustments, the regression equation relating LWC to height for St-Sc was separated into two equations: one for St and another for Sc. The equation for As-Ns was also separated into two equations: one for each. The coefficients for the four regression equations are given in table 3. The common form of these equations is shown below the table. Given the relationship between LWC and height Z, we had no difficulty in determining the level at which each of the mean radii listed in table 1 was located. The knowledge of this location is important in our procedure for finding drop-size spectra at different levels in a cloud.

TABLE 3. REGRESSION COEFFICIENTS FOR LWC (W, g m^{-3}) AS A FUNCTION OF HEIGHT (Z, m) ABOVE THE CLOUDBASE

Cloud Type	A(0)	A(1)	A(2)
Stratus	0.1193	1.99E-3	-1.4752E-6
Altostratus	0.1938	8.2627E-4	-4.7627E-7
Nimbostratus	0.2871	1.2441E-3	-7.0558E-7
Stratocumulus	0.0702	1.1706E-3	-8.6778E-7
Cumulus humilis	0.01846	1.2942E-3	-1.1721E-6
Cumulus congestus	0.0508	9.5268E-4	-2.2330E-7

$W(Z) = A(0) + A(1)Z + A(2)Z^2$

Figures 27 and 29 in Khrgian[2] depict the vertical profile of the mean radius distribution. Khrgian's figure 27 for the Sc cloud is reproduced here as figure 2. The figure shows that the mean (or mode) radius appears to increase linearly with height up to a certain level and then to change little or none with height to the cloud top. The radius profile, as with the LWC profile, can be explained in consideration of the microphysical processes taking place in clouds. In theory, a cloud droplet can keep on growing indefinitely as long as some negligible supersaturation exists in a calm zero-gravity environment. In nature, this indefinite growth does not occur; and the processes of collision, coalescence, and gravitation settling usually take a heavy toll of the large droplets. This incidence of nature is well illustrated in Khrgian's figure 28, which is reproduced here as figure 3. Note the profile of the maximum radii which the drop-size spectra of Cu clouds have reached at different heights.

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[2]A. Kh. Khrgian, Editor, 1963, Cloud Physics, Israel Program for Scientific Translations, Jerusalem, 392 pp

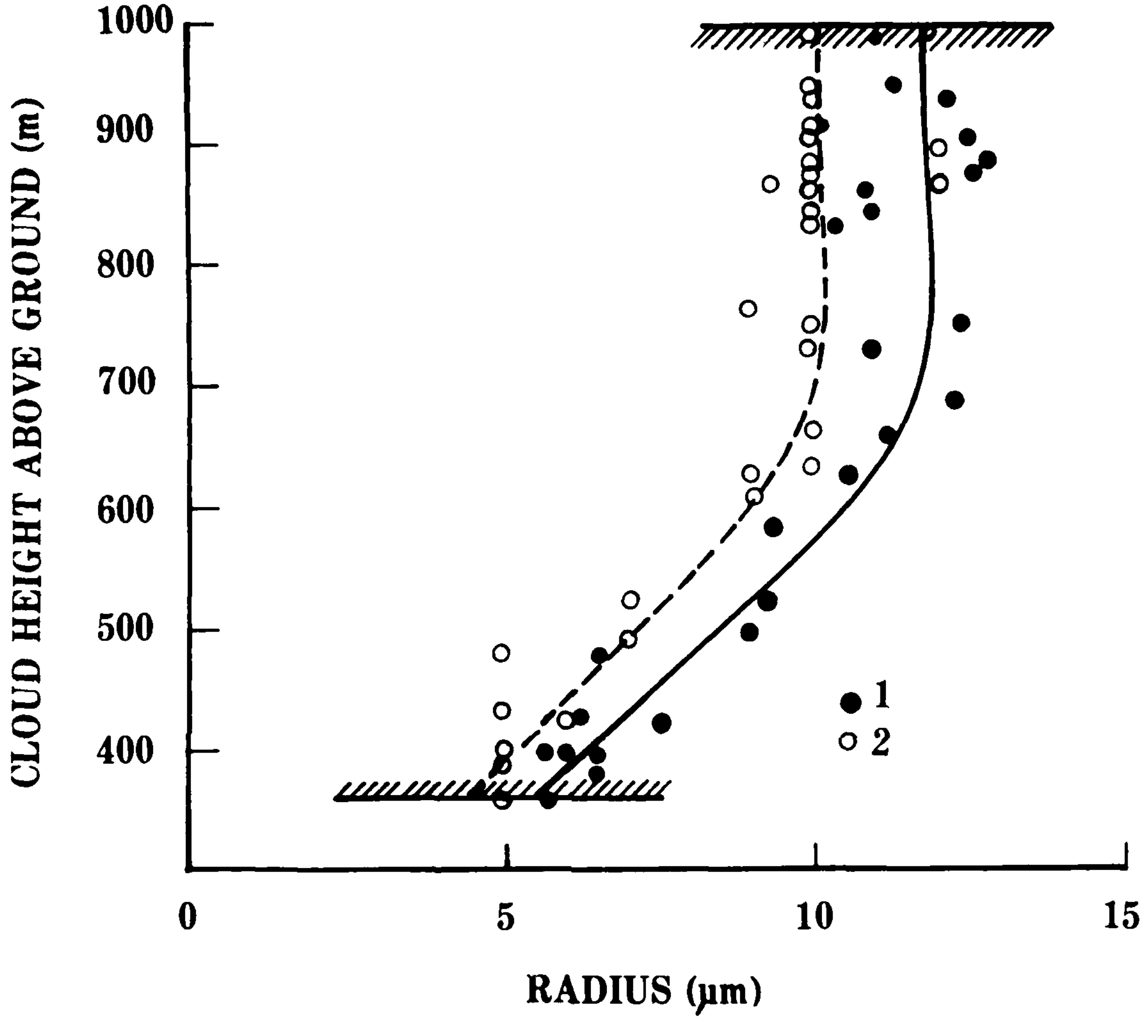

Figure 2. Distributions of mean (1) and dominant (2) droplet radii in Sc cloud layers (from Khrgian).

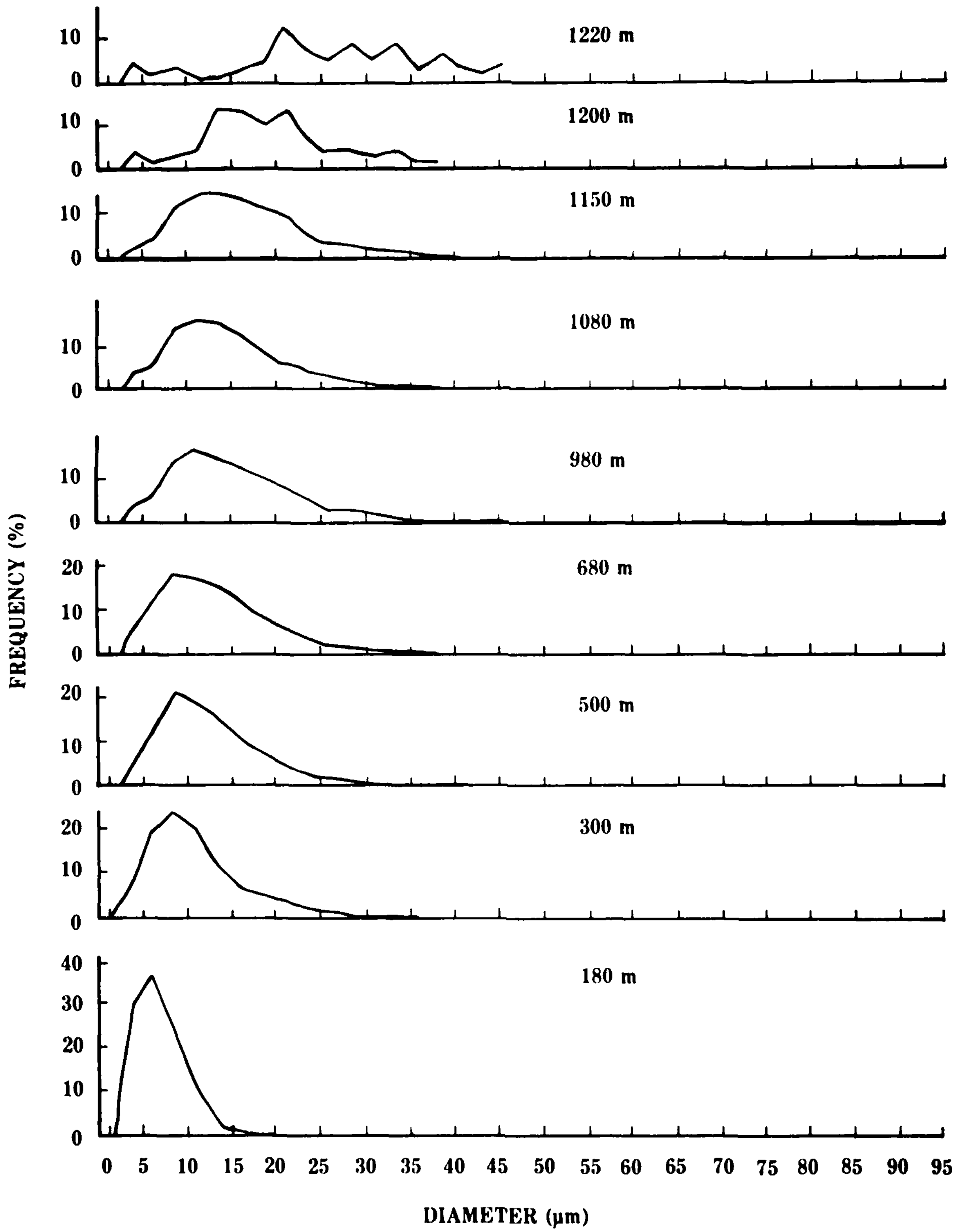

Figure 3. Percentage drop-size distributions versus height above the cloudbase in Cu clouds (from Khrgian).

To construct our mean radius profile, we can use the prior knowledge of where the mean radii of our model clouds were located in the plot of LWC versus height, as illustrated by figure 1. From the same plot, we can tell where the maximum LWC was, and the mean radius could be expected to stop growing from that height on and then remain unchanged to the cloud top. However, we do not know yet what the size was of the maximum mean radius at that height.

In table 3, note that at the cloudbase, that is, Z = 0, liquid water is still appreciable (partly caused by curve fitting) in some clouds. Since we did not know the number concentration, but recognized that the drop-size spectrum is usually rather narrow (as evidenced in figure 3) due to the continual influx of fresh cloud condensation nuclei as well as the entrainment of dry air from below, we arbitrarily assigned mean radius of 1μm to the Cu hum whose LWC has the lowest value at the base. This value implies that the cloud has a number concentration of about 1983 cm^{-3}. In table 1, the cloud has an average concentration of 310 cm^{-3}. This value was used to normalize each of the number concentrations of the other five clouds to yield a factor which, upon multiplication by 1983, would presumably give the number concentration of a cloud at the base with reference to that of the Cu hum. Since the LWC and particle concentration were given, the mean radius at the cloudbase, Z = 0, was readily found by means of equation (3). With the mean radius at the base so established, a line was drawn to connect this mean radius to the mean radius at the level previously located; then the line was extended to intersect the height of maximum LWC at which the maximum mean radius would now become known. The regression coefficients for the mean radius as a function of height are tabulated in table 4; the regression formula is shown below the table. In the following section, we shall consider how to deduce the microphysical and optical properties of the model clouds.

TABLE 4. REGRESSION COEFFICIENTS FOR MEAN RADIUS ($\bar{R}$, μm) AS A FUNCTION OF HEIGHT (Z, m) ABOVE THE CLOUDBASE

Cloud Type	A(0)	A(1)	R_{max}
Stratus	2.0	0.016	13.5
Altostratus	2.0	0.005	6.5
Nimbostratus	2.5	0.009	10.5
Stratocumulus	1.5	0.016	12.5
Cumulus humilis	1.0	0.009	6.5
Cumulus congestus	2.0	0.013	30.00

$R(Z) = A(0) + A(1)Z$ for $\bar{R} \leq \bar{R}_{max}$

4. CLOUD MICROPHYSICAL AND OPTICAL PROPERTIES

After a good approximation is obtained to express the LWC and mean radius of a cloud as a function of height, equation (2) may be invoked to generate its drop-size distributions of the cloud at any class intervals and at any chosen height. From these distributions, the extinction coefficients can be calculated at any wavelength or spectral band chosen according to the Mie theory.

Drop-size distributions were calculated in 1μm radius intervals every 50 m for each of the six model clouds. An example of the computed drop-size distributions as percentage frequency versus height is shown in figure 4. If an imaginary curve is drawn intersecting the maximum radius of each distribution from the cloudbase to the top, the profile so produced resembles quite well the one for figure 3. After the distributions were obtained, the extinction coefficient at a wavelength, $K(\lambda)$, was calculated according to the following formula:

$$K(\lambda) = \Sigma\ \pi\ n_i Q_i(r,m,\lambda)\ r_i^2\ , \tag{4}$$

where n_i and r_i are the number density and radius of each size class i, respectively; and $Q_i(r,m,\lambda)$ is the efficiency factor for extinction, a function of r_i, complex refractive index m, and wavelength λ.

Since our present interest is in the visible, near-infrared, and middle infrared window regions, computations were made for the 0.55μm, 3.80μm, and 10.6μm wavelengths as an illustration. When these computations were completed, a plot of extinction coefficient versus height was made for each of those cloud types and at each of those wavelengths. Careful inspection of the finished plots disclosed the feasibility of a least-squares fit, thereby making it possible to avoid the use of lookup tables. After some experimentation with polynomials of different degrees relating extinction coefficient to cloud height, we found that polynomials of up to 6 degrees in the majority of cases would give nearly perfect correlation. Examples of the least-squares fit for the Cu hum at the three wavelengths are displayed in figures 5 through 7. The regression coefficients are tabulated in table 5; the regression equation for extinction as a function of cloud height and wavelength is shown beneath the table.

5. SUMMARY AND CONCLUSIONS

To formulate cloud optical models for central Europe, the Russian-measured data (the only and perhaps the best available) on cloud liquid water and mean radius distributions as a function of height were mated to the German-observed four cloud types (again the only and perhaps the best available) through a series of manipulations and adjustments. Through this procedure, we were able to generate drop-size distributions as a function of height with the aid of Khrgian-Mazin's one-parameter gamma distribution. With the distributions thus obtained, we calculated the extinction properties of the six cloud types in

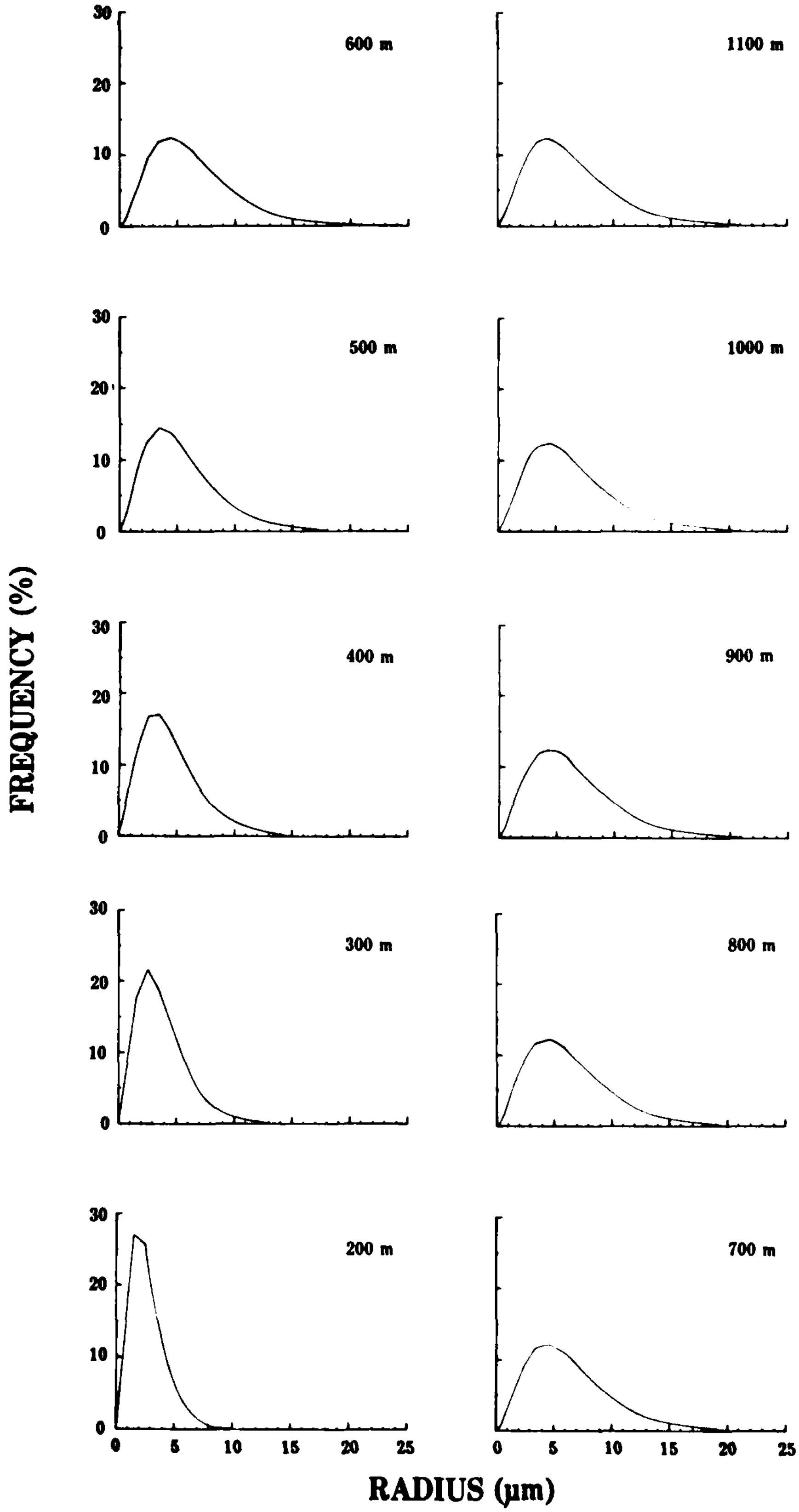

Figure 4. Calculated percentage drop-size distributions versus height above the cloudbase in model Cu hum.

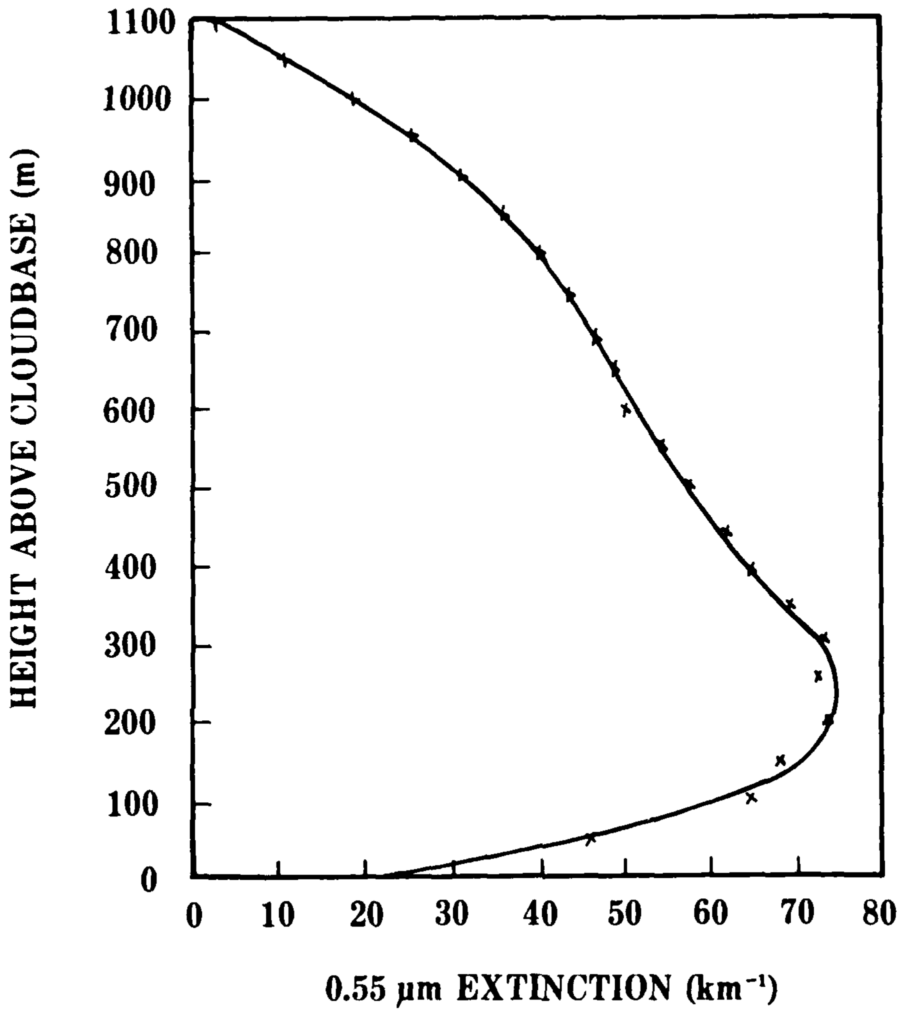

Figure 5. Least-squares fit to the 0.55μm extinction coefficients versus height above the cloudbase in model Cu hum.

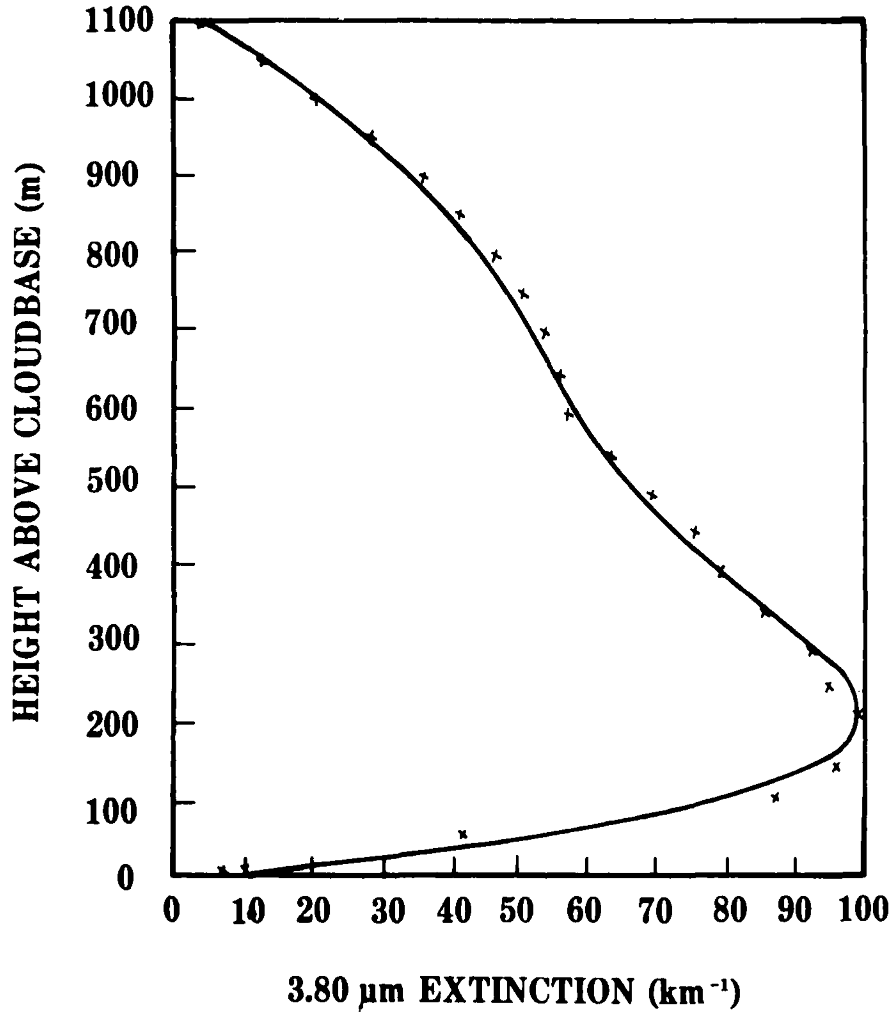

Figure 6. Least-squares fit to the 3.80µm extinction coefficients versus height above the cloudbase in model Cu hum.

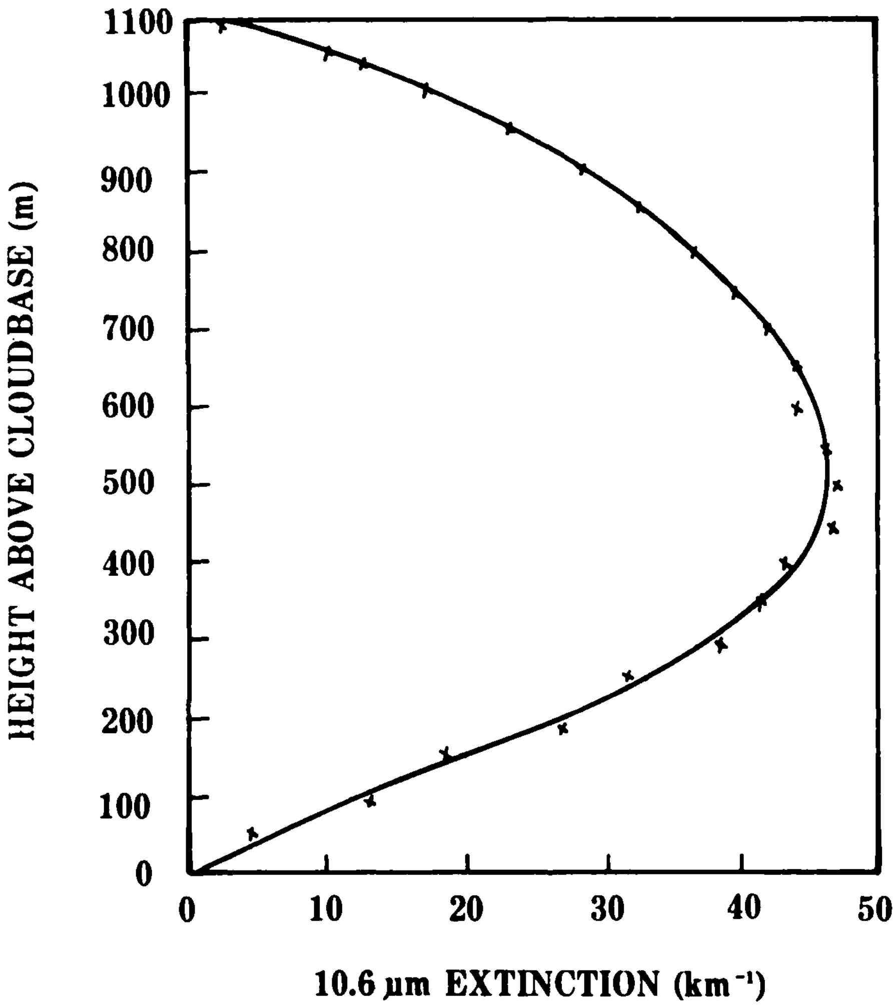

Figure 7. Least-squares fit to the 10.6µm extinction coefficients versus height above the cloudbase in model Cu hum.

TABLE 5. REGRESSION COEFFICIENTS FOR SPECTRAL EXTINCTION (K, m^{-1}) AS A FUNCTION OF HEIGHT (Z, m) ABOVE THE CLOUDBASE.

Cloud Type	A(0)	A(1)	A(2)	A(3)	A(4)	A(5)	A(6)
Wavelength λ 0.55μm							
Stratus	5.3744E-2	2.9313E-4	-1.1300E-6	1.6228E-9	-1.0421E-12	2.4192E-16	----
Altostratus	8.4451E-2	1.6549E-4	-4.7300E-7	4.4334E-10	-1.3851E-13	-2.0644E-17	1.2569E-20
Nimbostratus	1.0240E-1	4.8678E-5	-2.2195E-7	1.4506E-10	5.9393E-14	-8.7250E-17	2.1383E-20
Stratocumulus	3.6775E-2	1.6160E-4	-6.4666E-7	9.5298E-10	-6.4023E-13	1.6916E-16	-7.9924E-21
Cumulus humilis	1.8410E-2	6.6870E-4	-2.8406E-6	5.4478E-9	-5.4854E-12	2.7932E-15	-5.8271E-19
Cumulus congestus	3.3458E-2	1.3098E-4	-4.1528E-7	6.1166E-10	-4.6681E-13	1.7383E-16	-2.5043E-20
3.80μm							
Stratus	7.5099E-2	3.2061E-4	-1.7060E-6	3.3538E-9	-3.2719E-12	1.5721E-15	-3.0123E-19
Altostratus	1.1808E-1	2.2387E-4	-8.7996E-7	1.1298E-9	-6.6823E-13	1.7514E-16	-1.5665E-20
Nimbostratus	1.4155E-1	-5.0592E-5	-1.2280E-7	1.2715E-10	2.7470E-14	-6.6940E-17	1.7734E-20
Stratocumulus	4.9533E-2	2.0904E-4	-1.1626E-6	2.3531E-9	-2.3463E-12	1.1472E-15	-2.2267E-19
Cumulus humilis	3.8315E-3	1.1837E-3	-5.1096E-6	9.4660E-9	-8.6426E-12	3.6778E-15	-5.5775E-19
Cumulus congestus	4.1534E-2	2.0270E-4	-8.1463E-7	1.3590E-9	-1.1142E-12	4.3867E-16	-6.6426E-20
10.6μm							
Stratus	1.1269E-2	2.8659E-4	-6.0210E-8	-1.5274E-9	2.7747E-12	-1.8946E-15	4.5539E-19
Altostratus	1.9856E-2	1.2292E-4	-8.4779E-8	8.6563E-12	---	---	---
Nimbostratus	3.1907E-2	1.9632E-4	-1.1114E-7	-3.3987E-10	5.2528E-13	-2.7799E-16	5.0469E-20
Stratocumulus	6.8522E-3	1.5362E-4	7.5813E-8	-1.1430E-9	1.8885E-12	-1.2477E-15	2.9522E-19
Cumulus humilis	8.5792E-4	6.4122E-5	7.7271E-7	-2.9750E-9	4.4014E-12	-3.0626E-15	8.1541E-19
Cumulus congestus	3.7151E-3	1.4919E-4	-9.3486E-8	-1.2183E-10	1.8733E-13	-9.2167E-17	1.5939E-20

$K(\lambda, Z) = A(0) + A(1)Z + A(2)Z^2 + A(3)Z^3 + \ldots + A(n)Z^n$

table 1 at the 0.55μm, 3.80μm, and 10.6μm wavelengths. The natures of the original and derived data are such that these computations could be made by means of the convenient regression equations, which are expressible in polynomials of the following form:

$$P(Z) = A(0) + A(1)Z + A(2)Z^2 + \dots + A(n)Z^n \ , \qquad (5)$$

where P(z) is the relevant parameter which may be LWC or extinction coefficient. The transmission through a distance in cloud at any of the above wavelengths can be found analytically by means of the relevant regression equation for extinction. The optical depth $\tau(\lambda)$ through a path length from level z_1 to level z_2 is given by:

$$\tau(\lambda) = \int_{z_1}^{z_2} K(\lambda, Z)\, dZ$$

$$= \int_{z_1}^{z_2} \left[A(0) + A(1)Z + A(2)Z^2 + \dots + A(n)Z^n\right] dZ$$

$$= \left[A(0)Z + (1/2)A(1)Z^2 + (1/3)A(2)Z^3 + \dots (1/n+1)A(n)^{n+1}\right]_{z_1}^{z_2} \ ; \qquad (6)$$

and the transmissivity T is simply:

$$T(\lambda) = \exp\left[-\tau(\lambda)\right] \ , \qquad (7)$$

where diffused transmission due to multiple scattering has been neglected.

Equation (6) was used to estimate the approximate level at which a light beam entering the cloudbase can be detected at a brightness contrast threshold of 0.05 in the visible region. For comparison, we determined how far the beam would travel in a plane parallel atmosphere at the same 5 percent threshold value near the cloudbase. Table 6 shows the results of our computations.

TABLE 6. HORIZONTAL AND VERTICAL RANGES AT THE 5 PERCENT CONTRAST THRESHOLD NEAR THE CLOUDBASE

	Visual Range (m)	
Cloud Type	Horizontal	Vertical
Stratus	56	50
Altostratus	36	35
Nimbostratus	29	29
Stratocumulus	82	72
Cumulus humilis	163	77
Cumulus congestus	90	79

The table indicates that serious errors would result in using homogeneous cloud models. A comparison of the horizontal and vertical ranges shows that the last three cloud types appear to be quite inhomogeneous, an observation also noted in table 2. Even without the Russian observations of cloud liquid water, the general shape of the average LWC profile could be ascertained by merely considering the mixing and entrainment taking place at the upper and lower boundaries of a cloud. There will be a maximum somewhere inside the cloud, which presumably depends upon the cloud type. The average profile of cloud mean radius is also believed to be realistic. As cloud water increases with height, the droplets, and hence the mean radius, are expected to grow until they reach a point where the larger droplets can no longer be sustained by updrafts inside the cloud. At this point, the growth of the cloud mean radius either begins to taper off or it stops. As cloud water begins to decrease at higher altitudes, there is little chance for the mean radius to grow any more. It is on the basis of Russian and German observations as well as these considerations that we have proposed 6 one-dimensional cloud microphysical models which we hope will fill the gap which has long been felt in the modeling community and which is also found in our present EOSAEL.

Since the one-dimensional microphysical and optical model cloud types are represented by a number of simple regression equations in conjunction with the use of Khrgian-Mazin's[10] modified gamma distribution, we perceive little difficulty in implementing these cloud models on any computer. In the absence of observed cloud ceilings, the values of the cloudbase in table 2 may be used for the midlatitudes.

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[10]A. Kh. Khrgian and I. P. Mazin, 1952, "Distribution of Drops According to Size in Clouds," Trudy Tsen Aero Obs, 7:56-61 (English version)

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Fort Belvoir, VA 22060

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US Army Night Vision &
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Warrenton, VA 22186

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Warrenton, VA 22186

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APO Seattle, WA 98733

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Washington, DC 20310

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ATTN: DAMI-TS
Washington, DC 20310

HQDA (DAEN-RDM/Dr. de Percin)
Casimir Pulaski Building
20 Massachusetts Avenue
Room 6203
Washington, DC 20314

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Division of Atmospheric Sciences
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1800 G. Street, N.W.
Washington, DC 20550

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